The Cosmos

Planets & Life

PHYS 214

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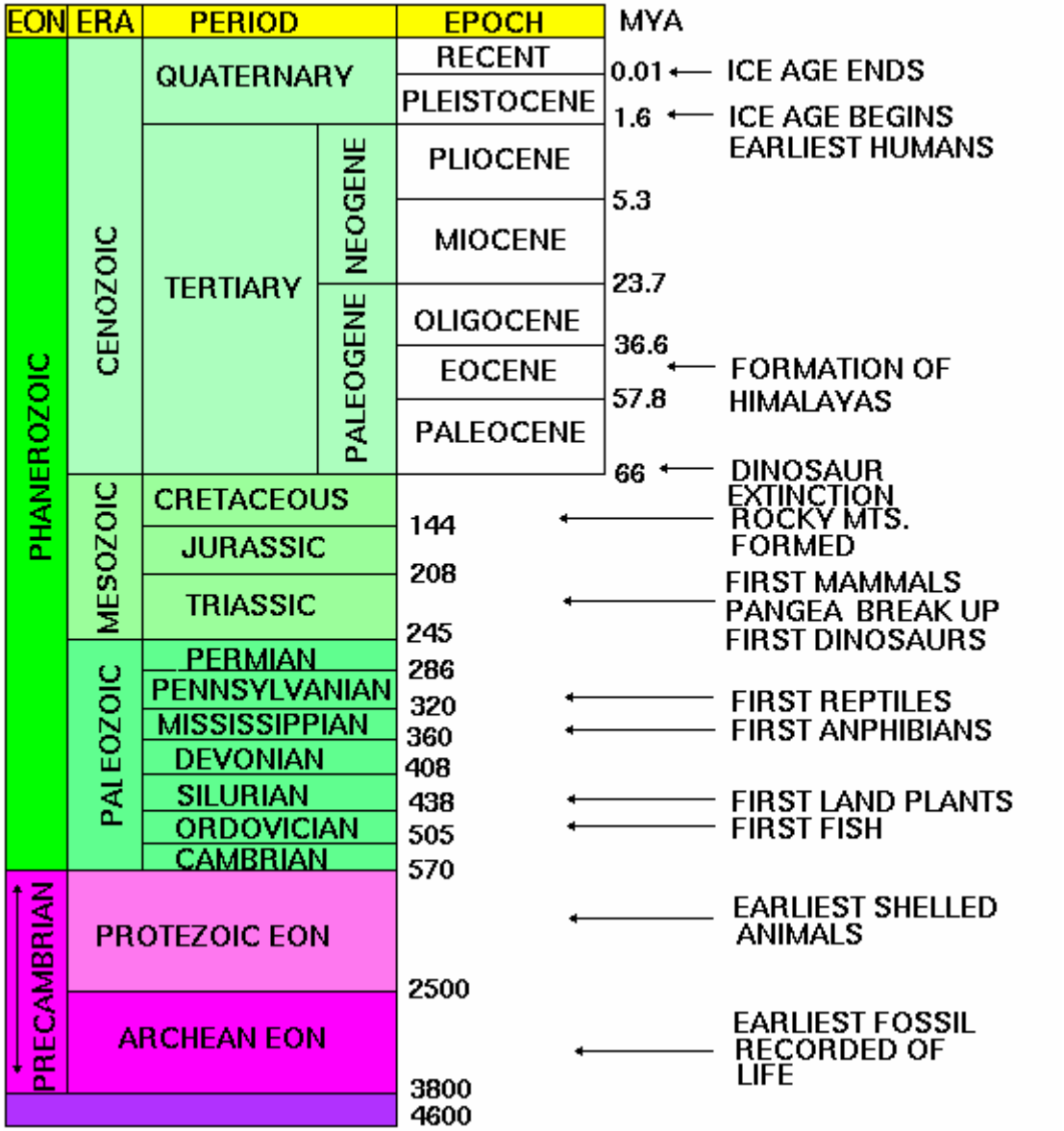
Please start all class related emails with "214:"

Today's Lecture

- Evolution of the cell
  - Possibility of panspermia
  - Brief mention of Earth geological history (we'll talk more about this later)
  - Prokaryotic cell, eukaryotic cell

Timeline of Earth History



Panspermia

- Some people believe that the origin of life on Earth form inanimate material is just too "impossible"
  - The suggestion is that somehow life on Earth was seeded from space – "panspermia"
- However, this is not a true solution to the problem posed – life must originate from somewhere
- Strongly advocated by the late Fred Hoyle & Chandra Wickramasinghe
- Technically the idea that life arose elsewhere and was transferred to Earth is called "exogenesis"
  - Panspermia is technically the idea that life (anywhere) is seeded from space itself
- Note that panspermia is also discussed in terms of supplying molecules that may have been necessary to produce life, rather than say depositing spores

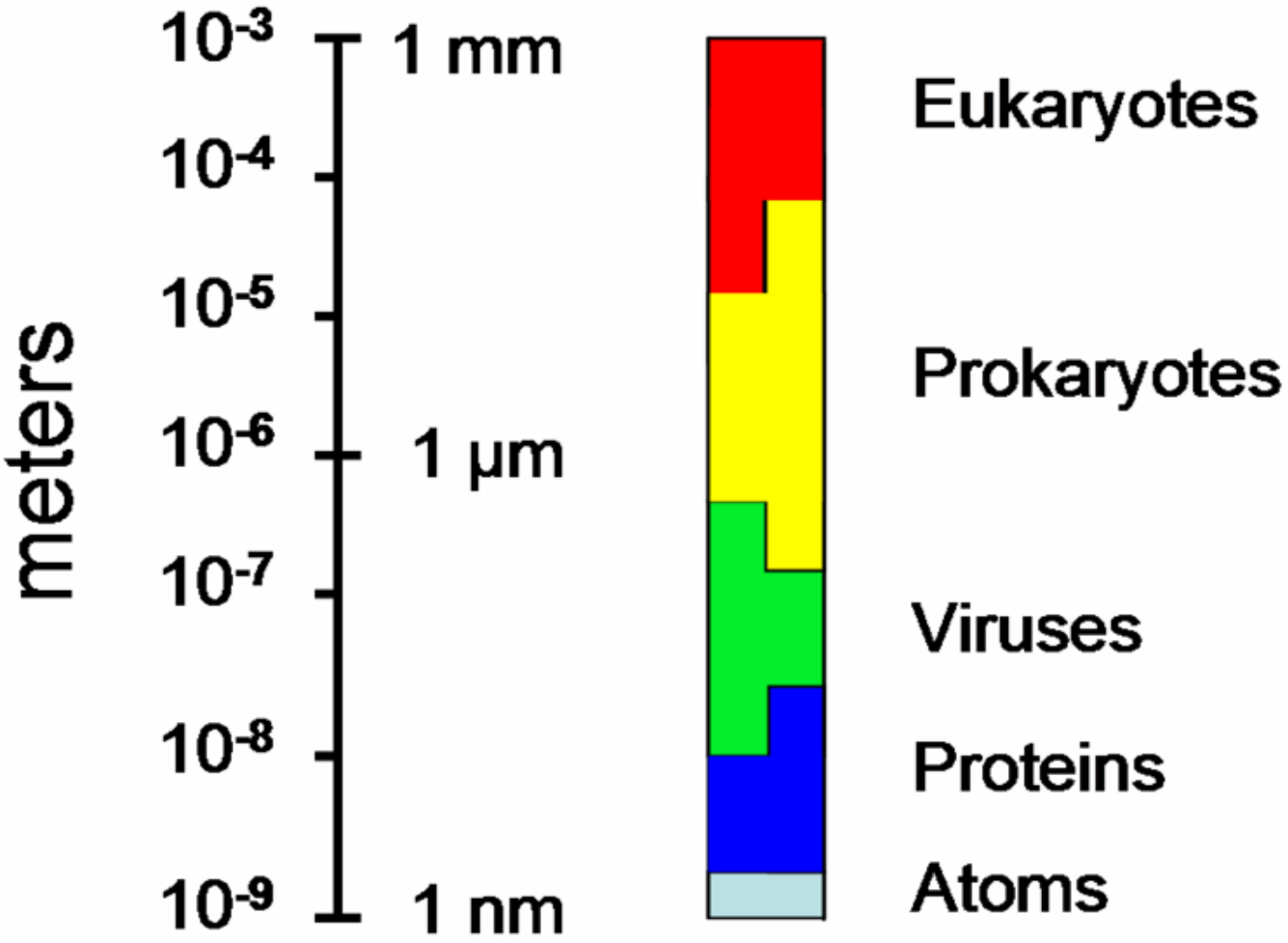
Material *does* transfer between planets

- We do know that a "significant" amount of material from Mars has reached Earth
  - Thus far 34 meteorites have been identified has having come from Mars
  - We also have around 40 meteorites which are known to have come from the Moon
- We can identify these objects as coming from Mars firstly by their young age (using radiometric dating) – normal meteorites were formed at the beginning of the solar system
  - Then apply a process of elimination
    - Venus's atmosphere and lack of cratering suggests it is a very unlikely source
    - Moon possible, but we know a lot about its composition which we can use
- The main source of energy to project these meteorites from Mars must be impact events
  - Very large ones might smoothly accelerate material to high velocities… Could very hardy organic material survive in deep space for long enough?

Starting point for cell "evolution"

- Primordial Earth has reached the point where water is freely available
  - Could either have been by minerals that release water or by resupply by comets
- Atmosphere contains most CO_2, N_2, with some CO and H_2O
  - Only trace amounts of oxygen
  - Probably still a very high flux of UV radiation from the Sun

Relative sizes of organic "building blocks"



Formation of the DNA molecule

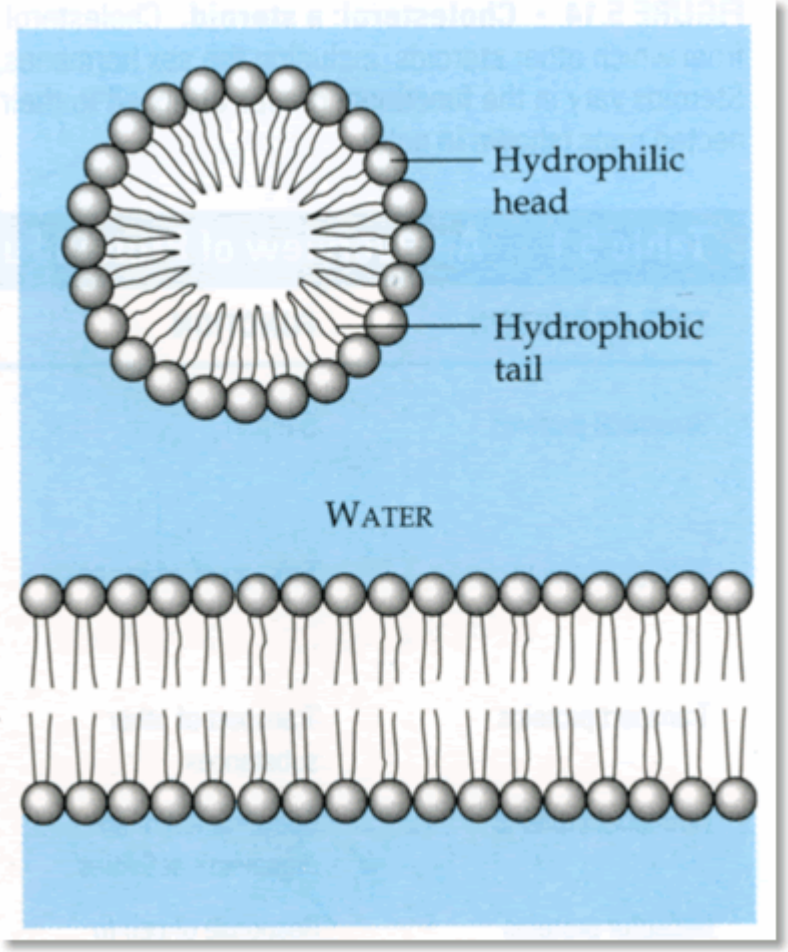
- The Miller-Urey experiment shows we can synthesize amino acids easily
- The "distance" between simple amino acids and DNA is vast though
  - DNA replication in itself is complex, involving enzymes (proteins) & RNA
  - Presents a 'chicken and egg' problem: the enzymes are needed to create the DNA, yet the enzymes cannot be reproduced without the information supplied by the amino acids
- RNA though is simpler, and also appears unique in that
  - RNA can code for genetic information
  - Certain forms of RNA are self catalyzing
- Could RNA actually have initially been the initial seed for the development of DNA?
  - Did life begin with RNA based organisms and evolve DNA later? "RNA world" hypothesis

Forming complex molecules

- Given appropriate groups in a monomer, polymerization can occur with the release of water
  - Hydroxyl groups, or a combination of carboxyl and amine groups for example
  - The newly bonded systems retain the capability for further polymerization
- The primary issue here is that water makes polymerization difficult
  - Breaks down polymers rather than building them up

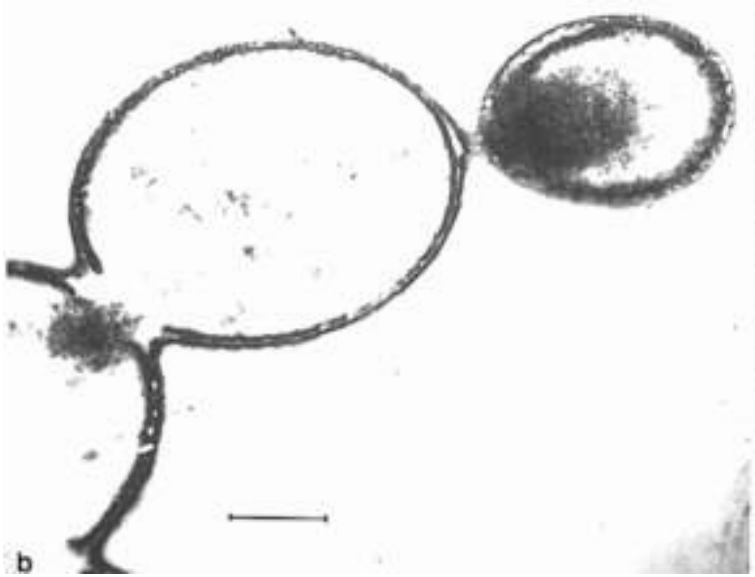
Creating something like a cell wall/membrane

- Amphiphilic molecules have a hydrophillic head & hydrophobic tail
- In presence of water they form monolayers as the hydrophilic heads try to sit on the surface of the water
  - Under disturbances the layers can form "micells" small spherical regions with hydrophilic surfaces
- Double layers can combine to enclose trapped regions of water "bilayer vesicle"



Microspheres

- In 1958, Stanley Fox created "proteinoids" by heating dry amino acids
- After dissolving these new molecules in water the proteinoids formed small spheres about 2 m in diameter – microspheres
- The microspheres mimicked biological membranes in that they could shrink or swell depending upon the surrounding salinity
- Amphillic molecules also may have been deposited on Earth by meteorites
  - Compounds on the Murchison meteorite demonstrate this behaviour

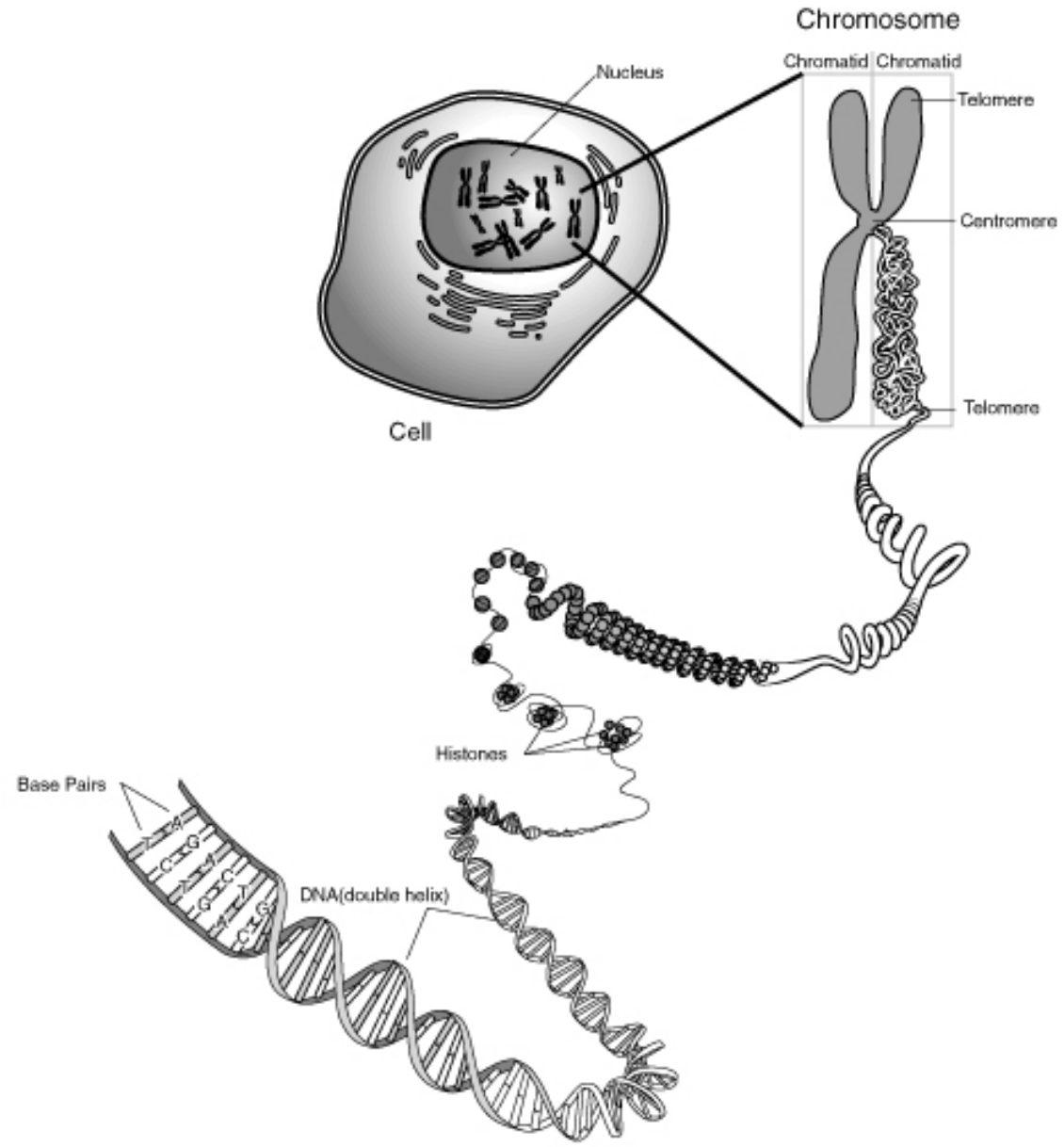


Role of minerals?

- Minerals ("clays") have frequently been cited as playing an important role in the development of complex organic polymers
  - **Protection**: small air pockets can be filled by organic material and then sheltered
  - **Support**: by providing a structure on which to accumulate and interact (amino acids concentrate on surfaces)
  - **Selectivity**: different crystal structures exhibit different chirality and this may have played a role in selecting the left-handed molecules on which life is based
  - **Catalysts**: Nitrogen is required in a form other than N2 – possible that iron oxide near vents of N_2 and H_2 allowed the production of biological useful NH_3

Cells

- **Cells** are the basic units of organisms
- Studies of **cell division** showed that genetic information is carried in the **chromosomes**, found in the cell **nucleus (**at least for eukaryotic cells**).** A chromosome is a very long, continuous strand of DNA
  - Human cells have 46 chromosomes (23 *pairs*, one of each pair from mother, one from father)
  - Bacteria typically have a single chromosome tethered to the membrane of the bacteria
- In turn, chromosomes are composed of **genes**; a gene is a sequence of DNA that encodes a protein (**one gene** for **each protein**); remember the **genetic code** discussed earlier, with each **codon** (triplet of DNA base-pairs) encoding one **amino acid**. One (human) chromosome contains several thousand genes

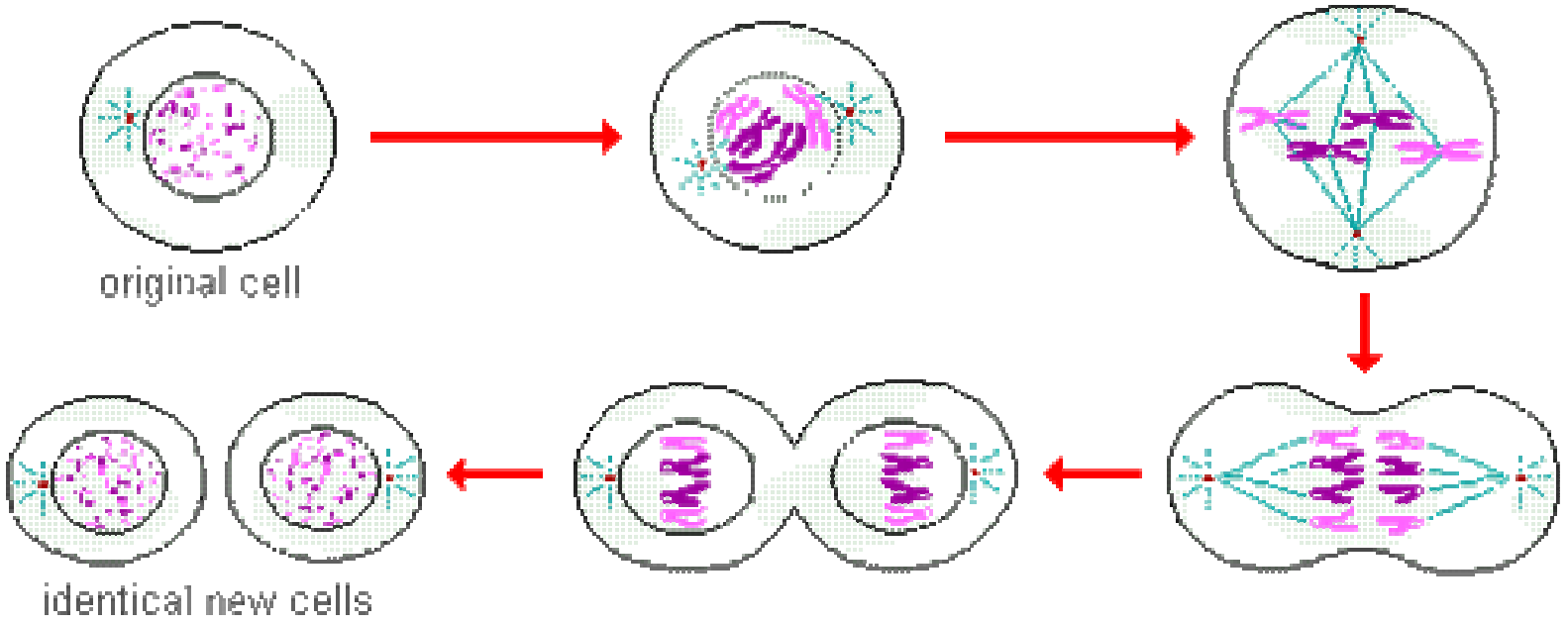

Chromosome
Chromatid
Chromatid
Nucleus
Telomere
Centromere
Telomere
Cell
Histones
Base Pairs
DNA(double helix)

Mitosis: cell divides to give two cells with the **same genetic information** as parent cell

-- in human bodies (eukaryotic cells), this is cell **replication**

-- in single-celled organisms, this is **reproduction**

Mitosis



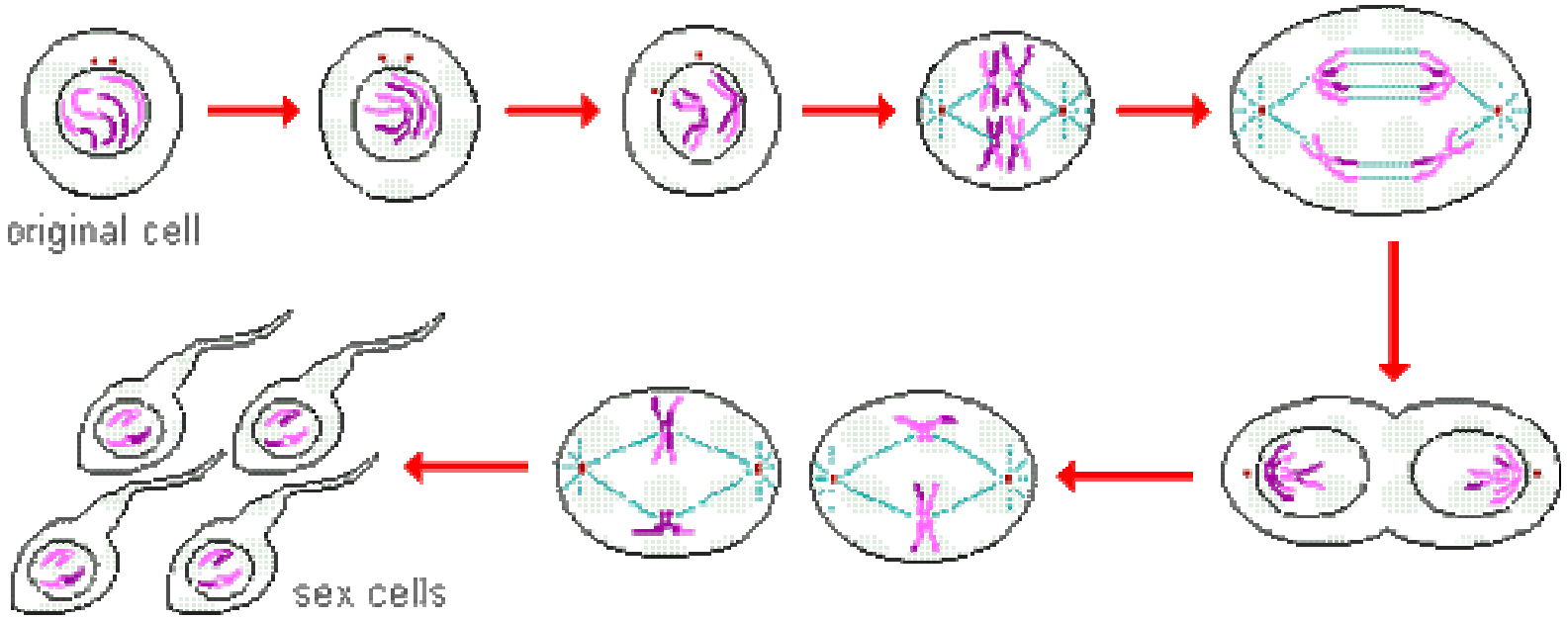
Mitosis movie

Meiosis: responsible for creating **gametes** (sperm or egg).

-- One cell divides to form 4 gametes with **half** the genetic information (chromosomes) in **each gamete**.

-- gametes are **not identical** to parent cell

Meiosis



Meiosis movie

- **Meiosis:** responsible for creating **gametes** (sperm or egg). One cell divides to form 4 gametes with **half** the genetic information (chromosomes) in each gamete

  -- in **sexual reproduction**, sperm and egg join to create a **whole** set of chromosomes

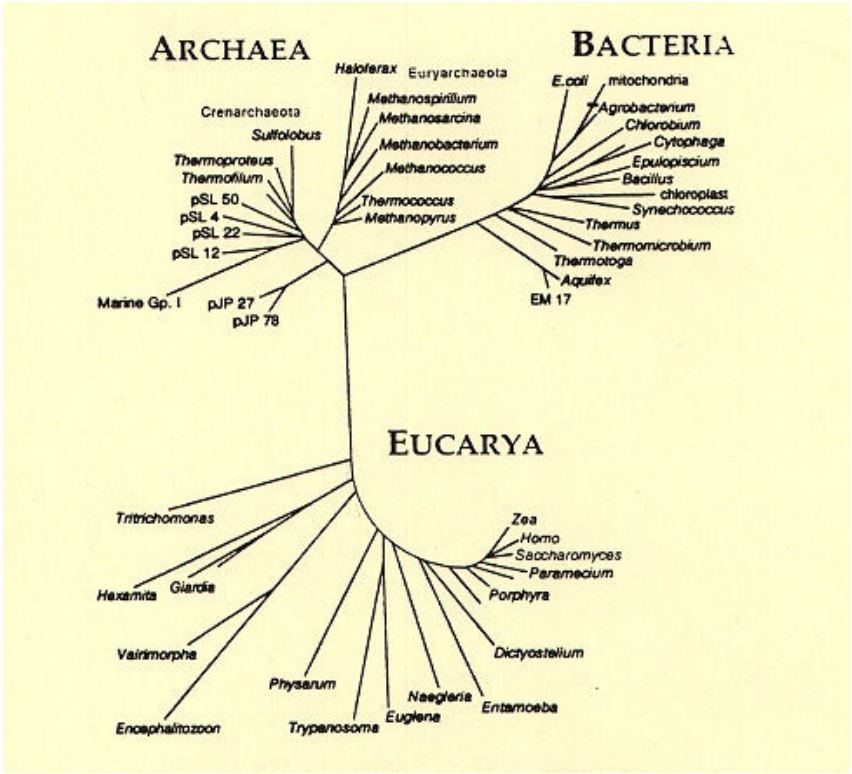
  -- each gamete ends up with **one chromosome** from each **homologous pair**, i.e. one chromosome from each parent. This happens at **random**

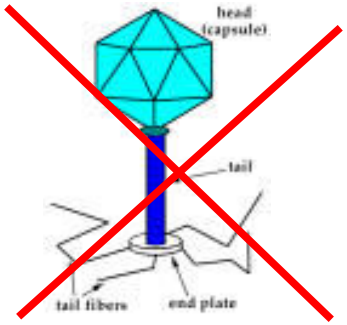
  -- this explains Mendel's results for dominant and recessive genes and **heredity**

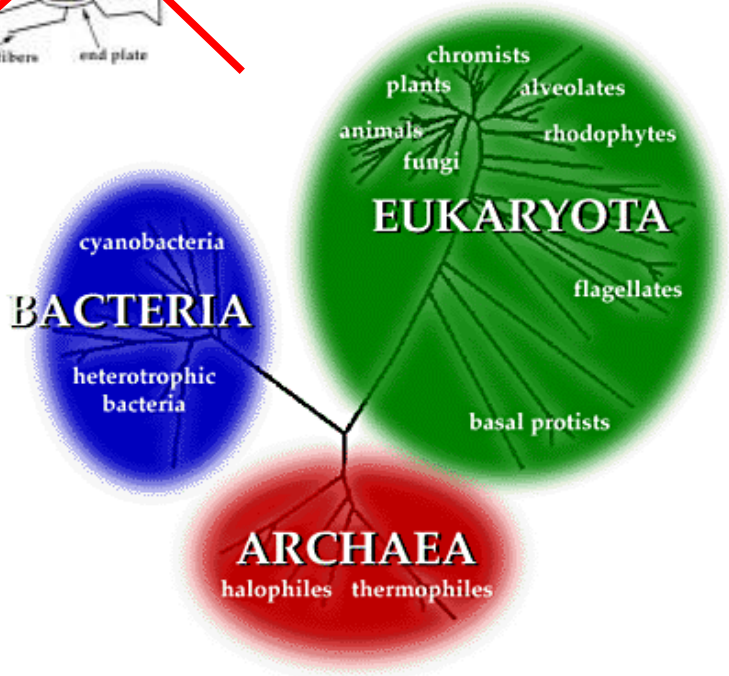
- So **chromosomes** carry the genetic information (**genes**), specificially via **DNA**

Domains of Life

-- **Eukarya**: plants, animals
-- **Bacteria**: simple, old organisms
-- **Archaea**: now recognized to be a new domain





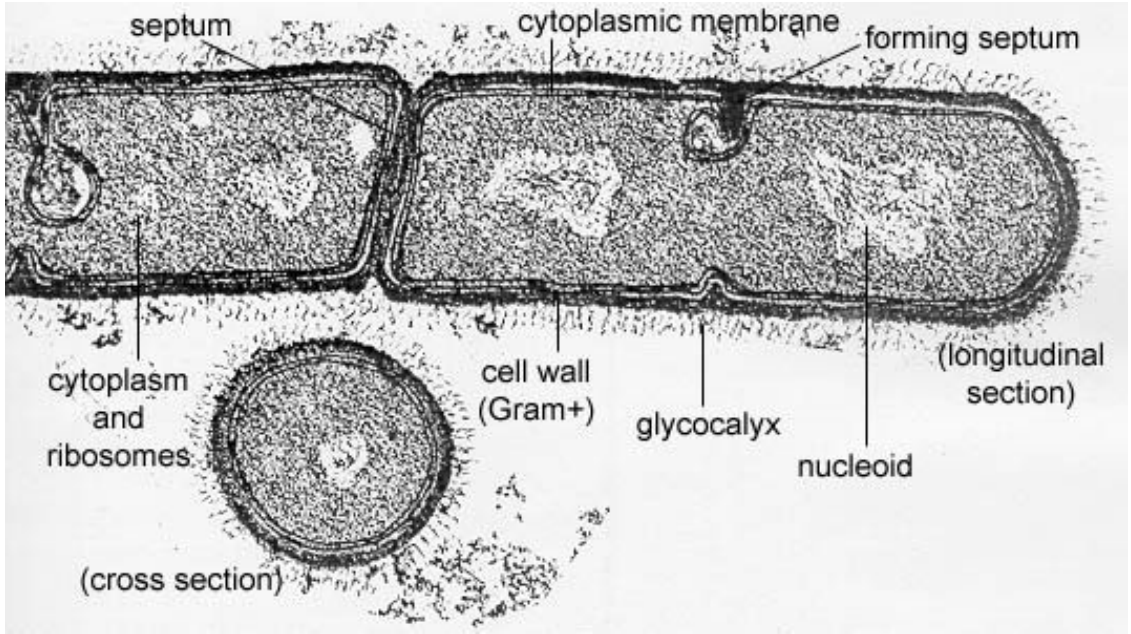


Prokaryotes

- Includes **bacteria** and **archaea**, the **oldest** life on the planet
  - Despite the inherent "difficulty" in forming DNA, bacterial life appeared on the planet at least 3.5 Gyr ago
- No **separate nucleus;** their DNA (in a single, long strand, with several thousand genes) is dispersed in the cell
- They don't have complicated internal structure of **eukaryotic** cells. But they do have DNA/RNA, and make their own proteins

Prokaryotic Cell

(*Bacillus megaterium*)



Bacteria: simple-celled organisms (e.g. blue-green algae, stromatolites) Fossilized remains of bacteria date to 3.5 Gyr ago

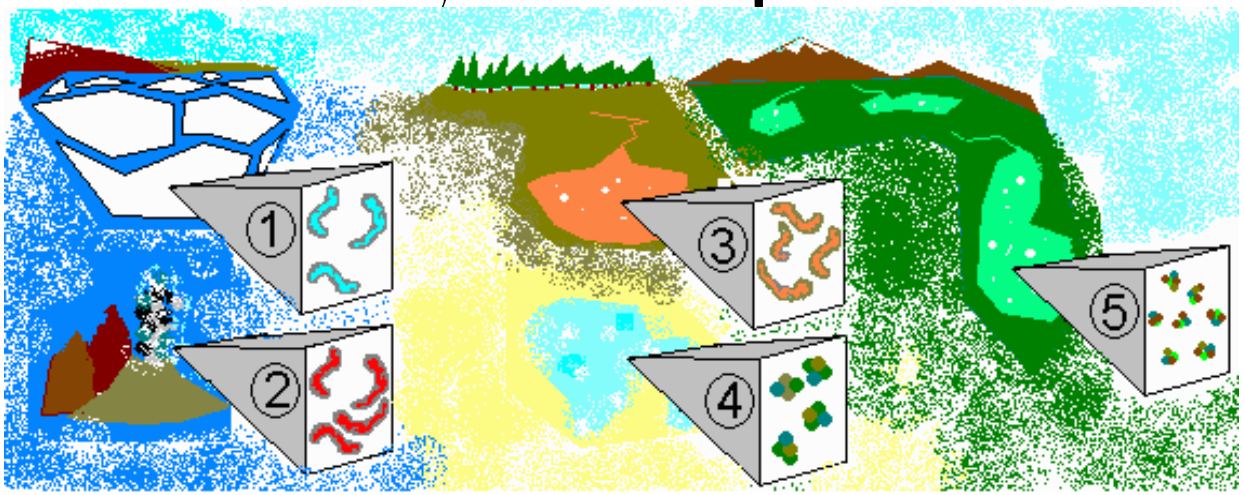
Stromatolites – fossil remains of early bacteria are very similar

Archaea: similar to Bacteria, but now considered a separate "domain" of life

-- distinction from bacteria is partially based on a chemically distinct cell wall

-- were initially categorized as a subclass of bacteria

- Archaea include many **extremophiles**



1) Psychrophiles
Microbes that live in cold environments like sea ice and the arctic and antarctic ice packs.

2) Thermophiles
Microbes that live in very hot environments like deep sea vents and volcanic lakes.

3) Alkaliphiles
Microbes that live in basic environments like soda lakes.

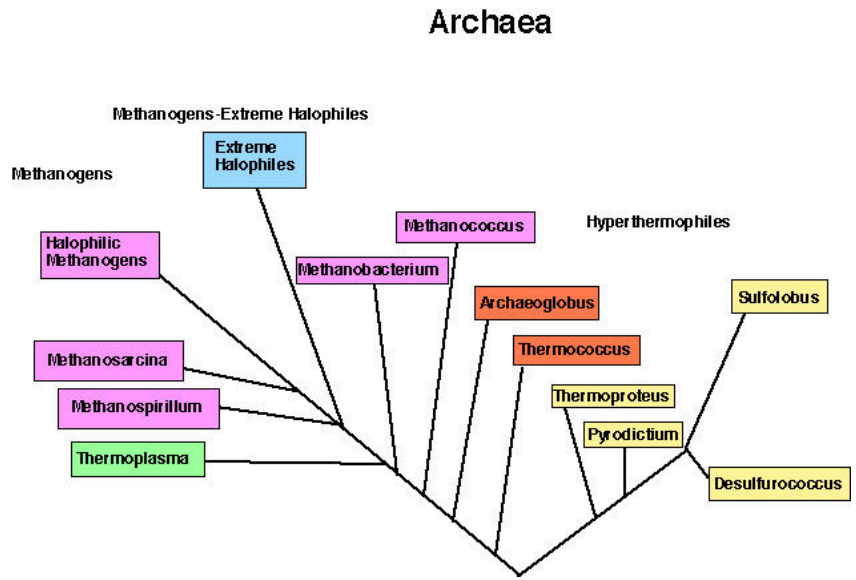
4) Halophiles
Microbes that live in very salty environments like salt lakes and salt mines.

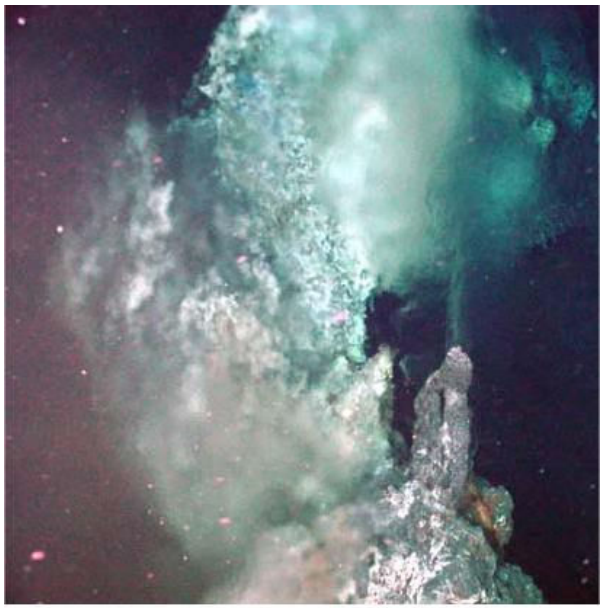
5) Acidophiles
Microbes that live in acidic environments like sulphur springs.

- **Archaea** are **simple**, thought to be **first life** to have arisen on Earth, when there was **little/no oxygen**

- Later they adopted **photosynthesis** to use Sun's energy. Earliest cells may have used H_2S instead of H_2O, freeing S instead of O_2

- Photosynthesis releases **oxygen**, building up atmosphere to present levels. This would have been deadly to (some/most) early Archaea (but not all). Archaea would have been present during **transition** to an oxygen-based atmosphere.

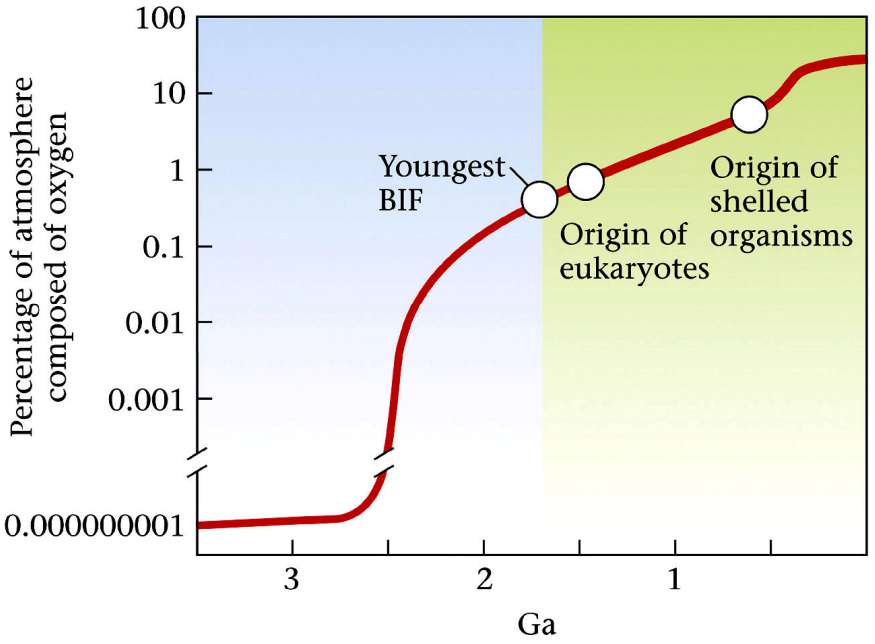




From NOAA: Erupting Volcanic Deep Ocean Vent

Changes in Earth's atmosphere

- The absence of oxygen forced early life to be completely anaerobic
- However, the geological record shows massive amounts of iron oxides ("banded iron formations"=BIF) deposited around 2.7 Gyr ago
- Cyanobacteria were the first organisms to develop photosynthesis and release oxygen into the atmosphere
- Believed that dissolved iron in the Earth's ocean reacted with the new oxygen at the surface
- Huge deposits may possibly be related to snowball-Earth events

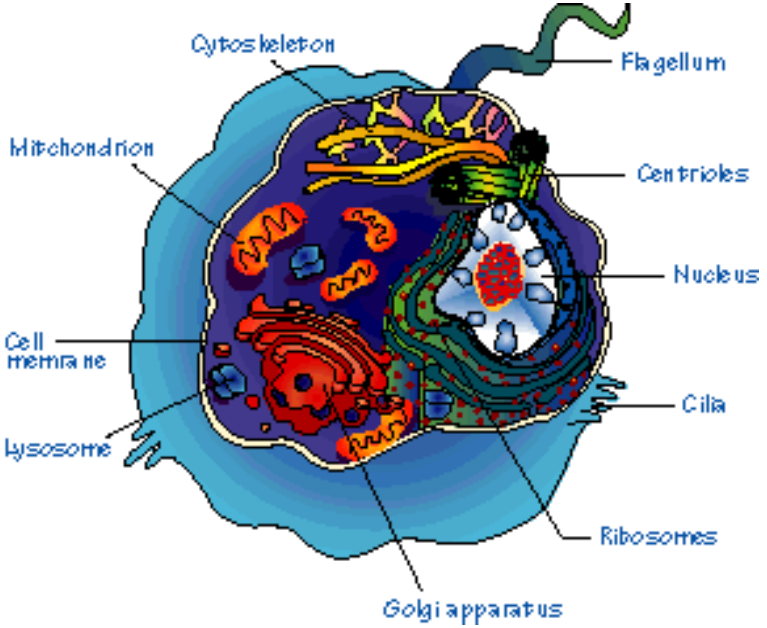


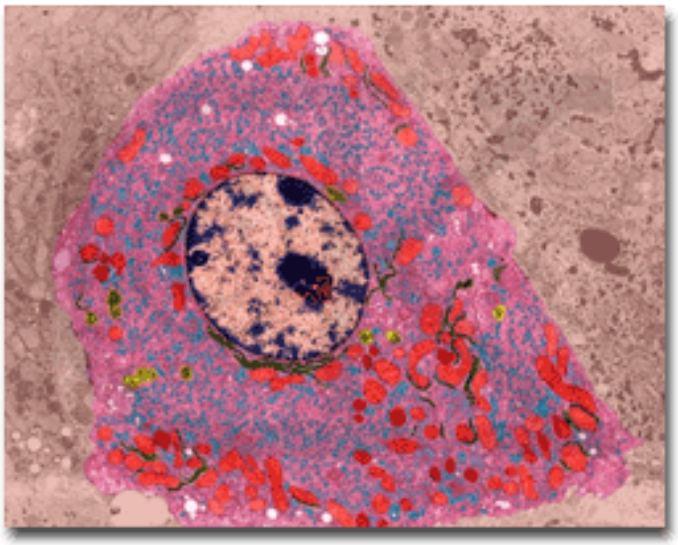
Eukaryotes

- Around when oxygen was becoming important (2-2.5 bya), eukaryotes arose to take advantage of it (~2.7 bya)

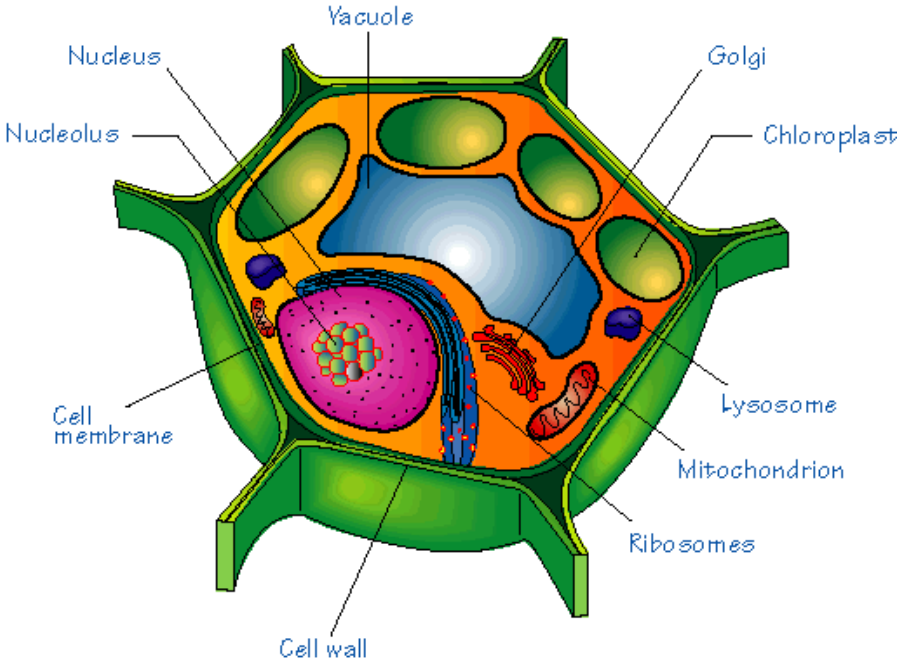
- Eukaryotes keep their DNA inside a central nucleus. They also have a lot more DNA than bacteria, and more complicated structure (e.g. sub-structures like mitochondria or chloroplasts) within "organelles"

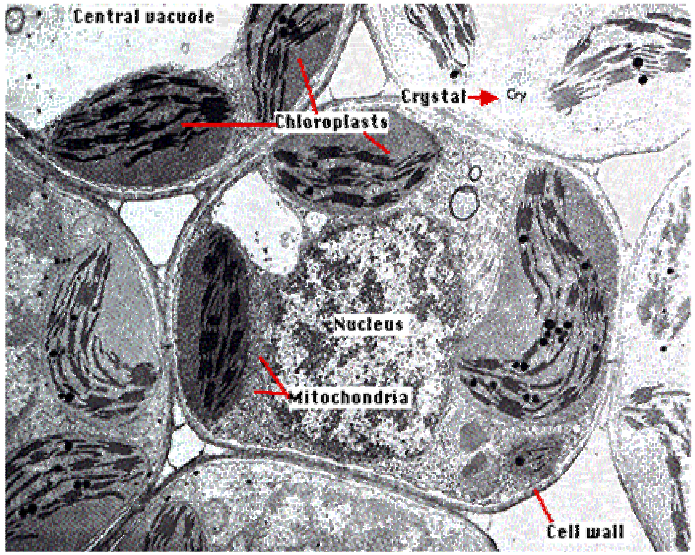
Eukaryotic Animal Cell





Eukaryotic Plant Cell





• Seems that **eukaryotes** arose from **prokaryotes** which developed **symbiotic relationships**, eventually residing within same cell membrane and specializing functions

-- e.g. chloroplasts/mitochondria with own gene systems

• Eventually cells formed relationships with other cells, producing multi-cellular organisms. A human has ~10^{13} cells cooperating together!

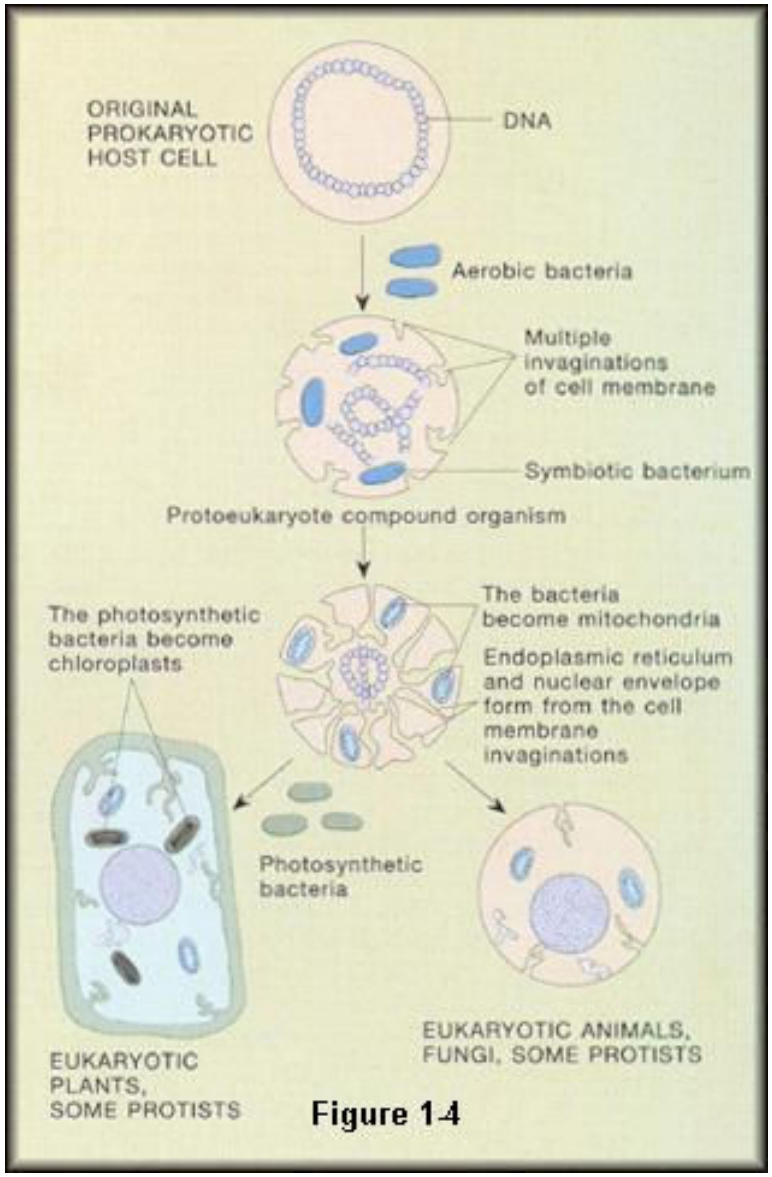


Figure 1-4

Reproduction:

• **Asexual**: prokaryotes and eukaryotes can reproduce asexually, creating identical copies (mitosis)

• **Sexual**: only in eukaryotic cells; results in new combinations of genes at each generation & more rapid evolution (meiosis)

Cambrian Explosion

- For billions of years, life on Earth consisted only of single-cell organisms, from which primitive multi-celled creatures developed (e.g. trilobites), and then later soft-bodied organisms like jellyfish
- But ~600 million years ago, there was an **explosion** of large numbers of complex creatures: the Cambrian Explosion.
- Not sure why it happened: more oxygen available, nutrients, rise of predators ("arms race")
  - This event has great significance in evolutionary theory, many different phyla ("body designs") arose, but there were remarkably few species
  - No new phyla have been created since!
- Nothing like it has been seen since

Life on Earth compressed into one year

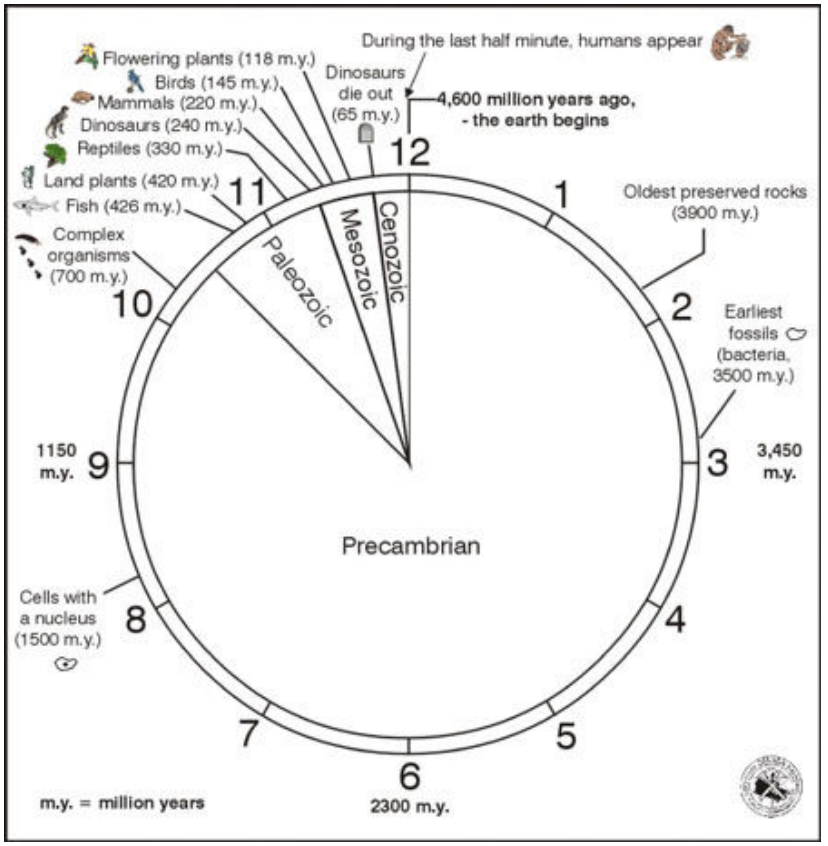
-- only bacteria/archaea until summer

-- oxygen-rich atmosphere through summer, but Cambrian explosion doesn't happen till Nov 13!

-- Dinosaurs: Dec 13-26

-- First humans: 6 pm Dec 31

-- Technological society: 11:59:59.9 pm Dec 31!



• Life may take **billions** of years to achieve intelligence (and only a short window to make contact).

Summary of lecture 20

- We have plausible arguments for how DNA may have arisen, but many key issues are missing
  - RNA may be the key
    - Potentially self catalyzing
    - Can carry information necessary for reproduction
- Early life relied upon the prokaryotic cell
- The evolution of the complex eukaryotic cell is widely believed to be due to the rise of symbiotic relationships between smaller and larger prokaryotic cells
- Complex animal life appears only 500 million years ago, even though the first bacteria appear 3,500 million years ago

Next lecture

- Guest lecture next Friday (8th March) by Dr Virginia Walker (Biology) on extremophiles